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Designing an Information Display for the Parafovia: Implications for the U.S. Army's Avenger Optical Sight

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Thirty subjects participated in a study comparing two methods of displaying visual information. Symbols on an Army missile-based weapon system, which are currently used to indicate critical system status, were redesigned in an effort to facilitate the uptake of information via the peripheral visual channel. Results revealed that it took significantly less time for subjects to make the correct decision using the enhanced display format.

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DESIGNING AN INFORMATION DISPLAY FOR THE PARAFOVIA:
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James . .* cath

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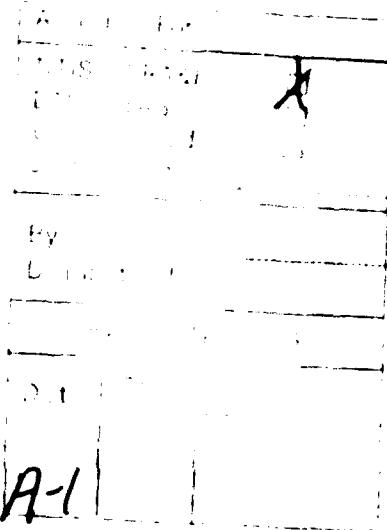
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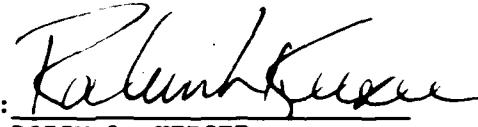
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INTRODUCTION

Missile-based weapon systems have evolved into very complex and sophisticated machines. The increased speed and accuracy of these systems has been accompanied by a proliferation of sensor technology, which has greatly increased the amount of information displayed to the operator. Thus, crews have more stimuli to attend to (increased task loading) and less time to allocate to them (increased speed stress). Ample evidence exists to indicate that these effects can increase operator errors and degrade decision performance (e.g., Conrad, 1955; Goldstein & Dorfman, 1975; Mackworth & Mackworth, 1958; Wright, 1974).

If a system performs poorly, the responsibility may lie with the machine, the operator, the environment, or some interaction among these elements. When the operator is identified as the cause, inferior judgment or decision making is often seen as the problem. Considerable effort has been directed toward correcting this problem through the development of machine-based decision aids.

As the name implies, decision aids were conceived as support systems for human decision makers. Often, however, these systems replace, rather than support, human judgment (Seilheimer, 1988; Cohen, 1987). Whether these devices will deliver the tremendous benefits expected of them remains uncertain. In a review of five decision aids for military environments, Barnes (1980) reported that "...there is little evidence that these aids would be useful in an actual operational environment" (p. 60).

Negative attitudes toward decision aids are partly fostered by a general lack of user acceptance (Tolcott & Holt, 1987). While the basis for this lack of user enthusiasm has not been definitively established, certain hypotheses have been suggested—the most basic being people's disinclination to acknowledge their own judgmental deficiencies (Einhorn & Hogarth, 1978).

Other explanations center about the fact that the plans or problem solutions generated by decision aids must still be accepted or rejected by the human user. Woods (1986) has pointed out that very little is known regarding how adept people are at discriminating between correct and incorrect machine solutions. Further, he raises the question as to whether an operator *really* has the authority to countermand machine output. Also, the fact remains that while users of machine-based decision aids often have little to do with generating a solution, they remain solely responsible for its consequences.

In working to overcome the difficulties associated with decision aids, one should not lose sight of the opportunity to aid the decision maker at more basic levels. To achieve maximum system performance, the interface between operator and machine must be designed to reduce predictable human error by considering human limitations in sensory, perceptual, and cognitive abilities. In applying this philosophy, the best return on investment may come from consideration of display design—because system engineers often misinterpret the role of displays. While the operational purpose of a display is to convey information to the user, we are reminded that a display is actually just an ordering of stimuli intended to be meaningful to the user. "Thus, when we discuss the organization of information, this is really a euphemistic way of referring to the organization of stimuli..." (McCormick & Sanders, 1982,

p.45). Viewed from this perspective, it is clear that display design should be driven, not as it almost always is, by the push of technology, but by the application of empirically derived principles of human perception and cognition. Designs that enhance the perceptibility of a display will benefit the user by freeing cognitive resources for other tasks.

With two major exceptions (absolute sensitivity and the perception of self-motion, or vection), visual functions are optimal in the central visual field. Because of this, the preponderance of vision and display research has historically addressed foveal vision. This is entirely the correct emphasis if the salient point of the research concerns tasks requiring discrimination of fine detail, color perception, or object motion. If, however, the task is one of detecting the presence of an alerting stimulus, it may be appropriate to consider the capacity of the peripheral visual channel. Thus, signaling an event occurrence by "turning on" an alerting stimulus in the visual periphery can enhance performance by reducing the foveal channel information load.

To apply this principle to an existing system, an experiment was conducted comparing subjects' performance of a binary classification task while using one of two symbol formats. It was hypothesized that performance with a display using alerting symbols prominently displayed in the periphery would be superior to that observed with a display that required this information to pass through the foveal channel, because the former would require a smaller investment in information processing time.

METHOD

The system selected for study was the U.S. Army's "Avenger." The Avenger is a line-of-sight air defense weapon consisting of a rotatable turret mounted on the bed of a high-mobility multipurpose wheeled vehicle. Attached to the turret are pods containing STINGER missiles. Inside the turret, a crew compartment provides the gunner with all controls and displays necessary for system operation.

The Avenger gunner's mission is to protect critical assets from attack by hostile aircraft. Friendly aircraft must not be fired upon, and enemy aircraft cannot be engaged unless the weapon system is functional. Thus, for each aircraft encountered, the gunner's ultimate decision is whether to engage. To aid the gunner in engaging enemy aircraft, the Avenger is equipped with a sight glass through which the gunner looks to acquire and track aircraft. Projected onto this transparent glass is a set of engagement-relevant symbols. Figure 1 illustrates both the physical layout of the optical sight and the display symbols.

Throughout the engagement and launching sequence, the Avenger gunner must constantly monitor several system states. For example, the two rings and center dot on the optical sight will move to indicate the target at which the missile's infrared seeker is aimed. The "cross hair" is stationary and indicates the central aiming point for the missile system. While the gunner manipulates the azimuth and elevation of the turret to place the cross hair over the enemy aircraft, he must also monitor the relative position of the two rings and center dot to verify that the missile is tracking the same aircraft that he is. During engagement but before firing, the gunner must also verify that four critical system criteria are met. On the sight, the status of these criteria is indicated by the presence or absence of four line segments just below the two rings. Concurrently, other system information is also being displayed on a control panel (e.g., system fault light, arm indicator, rotary

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wing or fixed wing lead angle and superelevation switchlight, etc.). While these indicators are being visually monitored, auditory messages (comprised of various beeps and tones) are also being presented, indicating that the missile has acquired a target, that the missile has locked onto the target, and that the target has been identified as friend, foe, or unknown. Control of the engagement and launching sequence is accomplished via the gunner's interaction with a hand-held computer terminal, a hand station (similar to an aircraft control yoke), two foot switches, a headset, the optical sight, a cathode ray tube display, and the control panel—comprising approximately 88 indicators, displays, switches, and controls.
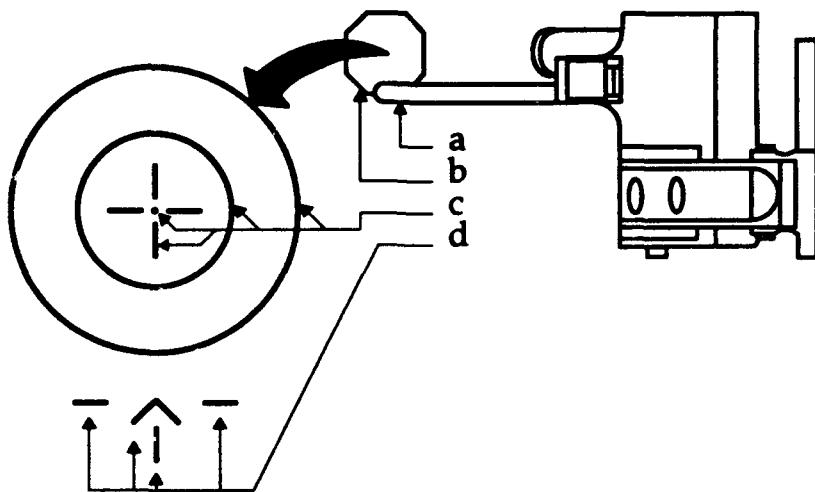

Figure 1. The Avenger optical sight and associated display symbols: (a) sight arm, (b) sight combining glass, (c) reticles, (d) status indicators for four critical system states. (System dysfunction is indicated by the absence of the normal status indication and there is no visual place marker that shows where the indication is absent from.)

Predictions are that a real conflict would require air defenders to face many enemy aircraft in a short period of time. Given the stress of battle and the complexity of the equipment, it is clear that the Avenger gunner would be performing his mission during conditions characterized by very high levels of mental work load and stress (i.e., circumstances counterproductive to good decision making).

To aid the gunner in reaching an engagement decision, an alternate method of displaying critical system status was conceived. Emphasis was placed on redesigning the status symbols to facilitate the uptake of this information by the peripheral visual channel. The enhanced symbols, shown in Figure 2, have two advantages over the symbols presently used (shown in Figure 1). First, anomalous system states are indicated by the presence of a display symbol, rather than the absence of a symbol (as is the case with the coding scheme now used). Second, the status indicators occupy approximately 30 times more retinal area than their counterparts in the conventional display, and they lie in the near peripheral field, uniformly distributed about 2° from the central fovea (when the operator fixates the center of the reticle). Based on these two improvements, it was hypothesized that the enhanced symbols would result in shorter engagement decision times than for the conventional symbols.
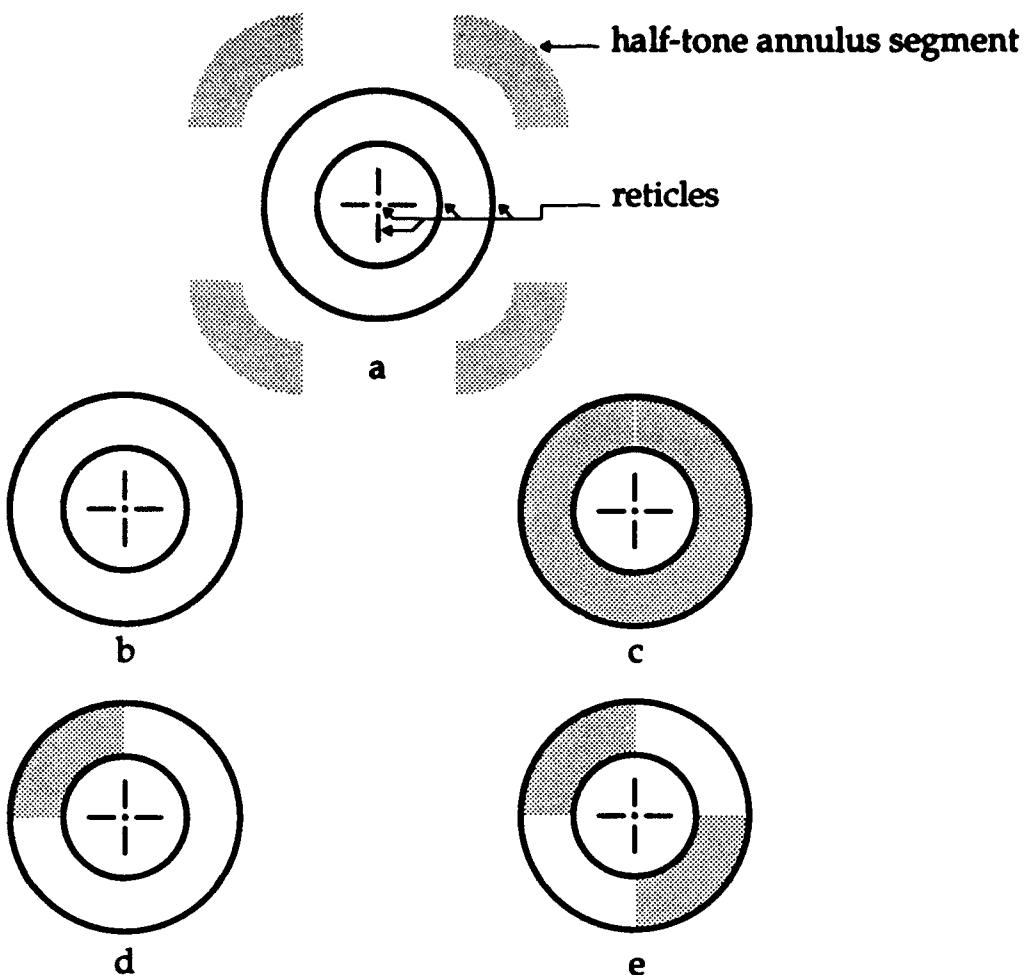
Figure 2. An alternate approach to coding four critical system states on the Avenger optical sight: (a) the display elements, (b) display indicating that all four critical systems are functional, (c) display showing that all four states are dysfunctional, (d) one system is dysfunctional, (e) two systems are dysfunctional.

Subjects

Thirty males between the ages of 18 and 30 participated in this study. All were active duty enlisted U.S. Army personnel stationed at Aberdeen Proving Ground, Maryland. The subjects were screened for a near binocular visual acuity of 20/20 or better. None of the subjects had any prior experience with the Avenger weapon system.

Apparatus

Vision screening was accomplished using a Bausch & Lomb Master Ortho-Rater, model 71-21-40-65. All display stimuli were presented using an Apple® Macintosh™ II computer, model M5400, and an Apple high-resolution monochrome monitor, model M0400. Subjects used an Apple mouse, model A9M0331, to make their responses. The displaying of stimuli, the control of stimulus and

inter-stimulus intervals, and the recording of responses and response times were under the control of the Macintosh II, running Apple's HyperCard™.

Procedure

The experimental methodology consisted of a binary classification task in which the subject classified stimuli as belonging or not belonging to a "target set." The target set was defined as any display that showed an engageable aircraft (helicopter) centered in the reticle and all critical system states in acceptable ranges. A nonengageable aircraft was defined as a fixed wing aircraft. The inclusion of engageable and non-engageable aircraft as stimulus conditions not only brought more real-world fidelity to the task, but prevented subjects from attending to system status indicators to the exclusion of aircraft information--a condition not representative of the operational task. Stimuli not belonging to the target set were those that either contained nonengageable aircraft or that showed one or more critical system states as being dysfunctional.

Two independent variables were manipulated. The first was a between-subjects manipulation of display type (DT)—enhanced status coding (DT1) versus the conventional status coding (DT2). The second was a within-subjects manipulation addressing display status (DS). Four levels of DS were chosen so that both type of aircraft (engageable and nonengageable) and system status (functional and dysfunctional) could be studied. They were

DS1. Engageable aircraft and all critical systems functional
DS2. Engageable aircraft and at least one critical system state dysfunctional
DS3. Nonengageable aircraft and all critical systems functional
DS4. Nonengageable aircraft and at least one critical system state dysfunctional

Subjects were told that the four status indicators represented four different critical conditions, which had to be met for engagement to be possible. Classification errors and response times constituted the dependent variables.

It was hypothesized that if subjects were allowed ample time to make their classification response (as long as 5 seconds), they would approach errorless performance of the classification task.

When all four critical system states were within acceptable limits and the aircraft was engageable (DS1), the enhanced display symbols appeared as in Figure 3(a). If the aircraft were engageable but one or more of the critical systems were dysfunctional (DS2), the enhanced display symbols could assume one of 10 possible configurations. For example, Figure 3(b) shows one possibility in which two critical system states are dysfunctional. Figure 3(c) illustrates the DS3 condition in which all critical system states are within acceptable limits but the aircraft is not of the engageable type. Figure 3(d) shows one of the 10 possible configurations meeting the conditions for DS4, in which the aircraft is nonengageable and at least one of the critical system states is dysfunctional (this example shows that three of the states are not within operating limits).

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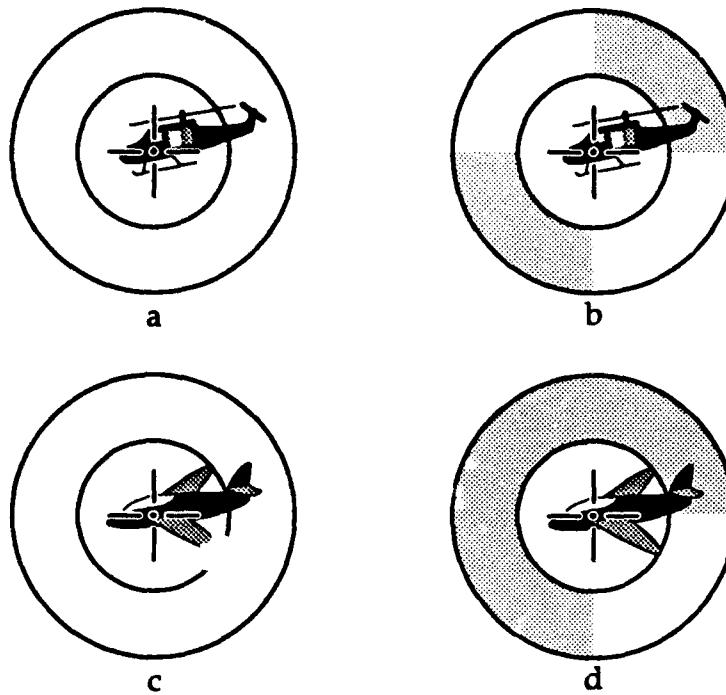
Figure 3. Examples of the enhanced display symbols for each of the four
display status conditions.

Figure 4 gives examples of the same four display status configurations
as they appeared, using conventional display coding.

Subjects, having been randomly assigned to one of two equally populated
experimental groups, were tested for near binocular visual acuity and then
seated 24 inches from the computer display. At this distance, the display
elements subtended the same visual angles as those present for an Avenger
gunner using the actual sight. The subjects were then read a standardize set
of instructions. During this initial instructional phase, subjects were
provided hard copy representations of displays, and the meaning of each
display symbol was explained.

The "positive" stimulus set (DS1) was discussed and examples were shown.
Subjects were then instructed about the binary classification task and were
familiarized with the use of the computer mouse as a response device. A
single press of the mouse button was used to identify a display as belonging
to the positive stimulus set (a target). Two presses (a "double click")
indicated that the display was not a member of the positive stimulus set.
Response latencies were calculated from the onset of the stimulus until the
first press of the mouse button. The second press (in the case of a double
click) was used only for identifying the response type. For the computer to
interpret a response as a double click, the second press of the mouse button
had to occur within 500 ms of the first. Subjects were allowed to practice
making both single and double clicks until they were comfortable with both.

Next, subjects performed a number of simple reaction time trials. This
served two purposes. First, it provided experience in using the mouse in
response to a computer-generated display. Second, it made it possible to test
for the existence of any response bias resulting either from group differences

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in simple reaction time or from individual differences in making a one-click versus a two-click response. The procedure was as follows. Subjects performed two blocks of 20 simple reaction time trials using the computer mouse as the response device. In one block of 20 trials, a single click was made in response to the onset of a computer-generated stimulus. In the other block, the same stimulus was used, but the response was a double click. The order of presentation of these blocks was counterbalanced. Examination of the scores revealed that no significant response bias existed between groups of subjects or between response types.
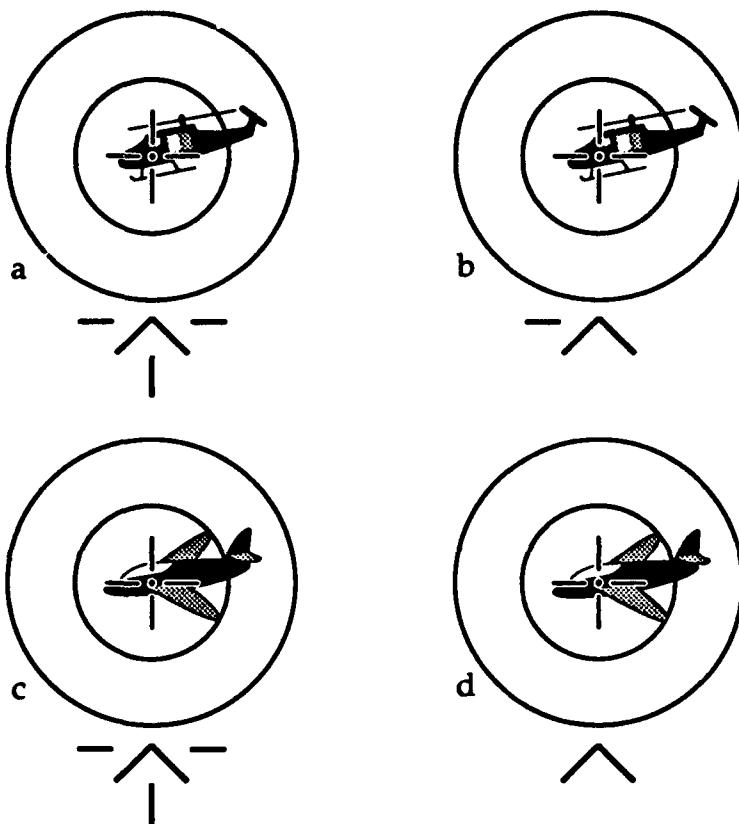

Figure 4. Examples of the conventional display symbols for each of the four display status conditions.

Instructions were then given addressing the critical aspect of speed-accuracy trade-off (Wickens, 1984). Briefly, the subject was told that his foremost responsibility was to classify the stimulus correctly. Making this correct classification as quickly as possible was referred to but in such a way as to be clearly interpretable as secondary to accuracy of performance.

Following this instruction period, subjects received training that consisted of 20 trials--five stimuli from each of the four DS configurations. The subject's classification response caused the display to blank and a 3-second interstimulus interval to begin. Two seconds into the interstimulus interval, a tone sounded, alerting the subject that a new trial was to begin in 1 second. Feedback was provided by the computer following an incorrect response. Following the last training trial, any stimuli that had been incorrectly classified were automatically displayed, allowing the experimenter

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to discuss the error(s). Subjects who correctly classified at least 18 of the 20 training stimuli (90% correct or better) proceeded to the testing phase. Subjects who incorrectly classified three or more of the training stimuli repeated the training session until they met the 90% correct criteria (no subjects required more than three training iterations).

The testing phase proceeded much as the training phase. Ten stimuli were presented for each of the four display status conditions, resulting in 40 experimental trials per subject. Thus, each display status condition was equally represented in the global stimulus set. The sequence of presentation for the 40 stimuli was randomized. No feedback was provided for incorrect classifications during testing.

RESULTS

Training

Summary data about the frequency of classification errors during training are presented in Table 1. The performance criteria established for advancement from training to experimental sessions (90% correct or better) meant that subjects could not proceed to the experimental trials until they completed a training session in which they made no more than two errors. Table 1 shows that 100% of the subjects assigned to the enhanced display (DT1) reached the criterion in one training session. Forty percent of the subjects assigned to the conventional display (DT2) required more than one session.

Table 1

Frequency of Classification Errors (by Display Type) During Training

| | | Error frequency | | | | | | | | | | |
		0	1	2	3	4	5	6	7	8	9	10
Enhanced display	Number of Ss	6	6	3								
	Percent of total	40	40	20								
Conventional display	Number of Ss	5	3	1	1	0	2	1	0	0	1	1
	Percent of total	33	20	7	7	0	13	7	0	0	7	7

Percentages have been rounded to the nearest whole integer.

Testing

Summary data about the frequency of classification errors by display type during testing are presented in Table 2. The subjects assigned to the enhanced display group committed exactly the same number of classification errors (six) as did the group assigned to the conventional display. As predicted, the overall experimental error rate (12 errors in 1,200 trials) was too small to lend itself to analysis.

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Table 2

Frequency of Classification Errors (by Display Type) During Testing

		Error frequency		
		0	1	2
Enhanced display	Number of Ss	11	2	2
	Percent of total	73	13	13
Conventional display	Number of Ss	10	4	1
	Percent of total	67	27	7

Percentages have been rounded to the nearest whole integer.

During the experimental session, each subject generated 10 response times for each of the four levels of DS. These were averaged, yielding one mean score per DS per subject. The resulting average response times and their associated standard deviations are provided in Table 3. These times were subjected to an analysis of variance with display type representing the between-groups variable and display status being the within-groups variable. Only the main effect for display type showed a significant variation, $F (1,28) = 10.825$, $p < .01$ (mean classification times were 555 msec for the enhanced display and 873 msec for the conventional display; standard deviations were .083 and .392, respectively). The two symbol sets were differentiated by a 318-msec difference in response time to the classification task. All other effects failed to reach significance at the .05 level of confidence.

Table 3

Response Time Means and Standard Deviations
by Display Type and Display Status

	Display status	1	2	3	4
Enhanced display	Mean	.566	.537	.602	.515
	Standard deviation	.075	.088	.068	.083
	Display status	1	2	3	4
Conventional display	Mean	.944	.888	.879	.782
	Standard deviation	.326	.525	.316	.387

DISCUSSION

Classification errors were committed so infrequently as to preclude their analysis. This attests to the success of the training received before testing and was not an undesirable outcome in that response time became the sole viable dependent measure. Being a continuous variable, response time may afford greater sensitivity than a discrete measure of error frequency.

Subjects assigned to the conventional display format (DT2) took more than 1.5 times as long to respond than those assigned to the enhanced display format (DT1). These results are consistent with the hypothesis that information processing time would be less for the subjects using the enhanced display. An alternate explanation is that the longer response time observed during the conventional display condition resulted from the necessity of an additional saccadic eye movement. Because the conventional status indicators are small and lie more than 2° of visual angle from the center of the reticle, it is likely that all the information necessary for making the classification decision could not be obtained from a single fixation of the conventional symbols. The enhanced design, however, allows the status information to be input through the peripheral channel while the point of gaze is maintained at the center of the reticle. Thus, both types of information can be obtained from a single fixation. However, even after allowing for this additional eye movement, response time was still considerably less with the enhanced display. This evidence leads to the conclusion that partial, apparently automatic processing of the enhanced display was sufficient to permit a much faster wholesale analysis of the stimuli than was possible with the conventional symbols. This agrees with evidence for automatic processing of peripheral information found by Antes (1974) and Loftus and Mackworth (1978). It is also in concert with Navon's (1977) investigation of global visual perception.

Display status (the within-groups variable) had no effect on response time. This result can be explained in two ways. It may simply be that equivalent information processing times were required to respond to each status condition. Alternatively, the data may reflect an artifact resulting from the subject's strategy of viewing the stimuli. For example, recall that each stimulus was composed of two elements, the aircraft type and the status of the four critical systems. To classify a stimulus as belonging to the target set, the aircraft had to be a helicopter and all critical systems had to be functional. One-half of all stimuli (DS3 and DS4) contained a fixed wing aircraft and therefore could not be members of the target set. If a common subject strategy had been to look first for aircraft type, response times for these two display status conditions should have been significantly shorter than for DS1 and DS2 stimuli, which contained helicopters. The implication here is that the status of the system states would be irrelevant to the classification task for DS3 and DS4 stimuli because the classification would have already been made based on aircraft type alone. Conversely, stimuli from Display Status Conditions 2 and 4 contained at least one dysfunctional critical system. If the common subject strategy had been to look first at system status indicators, these two display status conditions should have produced shorter response times. Eye movement data were not recorded, so no objective measure was available to shed light on the question of subject viewing strategy. However, at the conclusion of the experiment, each subject was asked which display element (aircraft type or status conditions) was attended to first. Sixteen of the subjects reported first attending to the aircraft, while 14 reported looking first at the status conditions. Were this actually the case, it would explain the failure to detect any significant group difference in response time between display status conditions. The validity of these subjective reports, however, cannot

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be established, and the reason for the lack of significant response times between display groups remains equivocal.

It is interesting to note the considerable variability in response times observed among subjects using the conventional display. This could be important in predicting performance with the conventional symbol set and may also have contributed to the fact that 40% of the subjects assigned to this display required more than one training session to reach the criterion.

CONCLUSIONS

The true value of this research lies not only in its support of the enhanced display format over the conventional format but in its compelling demonstration that basic principles of human perception and attention can make a practical difference when applied to real problems. Perception and attention form the foundation of our ability to extract relevant and timel data from the world around us. Displays that improve the acquisition and usefulness of these data will improve our ability to correctly respond to world.

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